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MINOR STUDIES FROM THE PSYCHOLOGICAL LABORATORY OF CLARK UNIVERSITY

Communicated by EDWIN G. BORING

XXIV. HIGHEST AUDIBLE TONES FROM STEEL CYLINDERS

By C. C. PRATT

The Psychological Laboratory of Clark University has a set of twenty-two steel cylinders designed for the determination of the upper limit of hearing. The set is similar to Koenig's and is manufactured by the Standard Scientific Company of New York. The present list price is \$75. The cylinders are computed by the manufacturers on the basis of a calibration made for a greater length of bar to give the frequencies for three octaves of the natural diatonic scale from $c^5 = 4096$ to $c^8 = 32,768$ vs. inclusive. Each cylinder is slightly grooved at its two nodal points and is suspended horizontally by loops of fine tough cord which pass about these grooves. A brass hammer is used to secure vibration.

We have attempted unsuccessfully to calibrate these cylinders by means of the Kundt dust method.¹ Schwendt has reported his experiments with this method in determining the frequencies of the Koenig high forks and cylinders.² The forks afforded him little difficulty, but only after many trials was he able to secure the Kundt dust figures from the cylinders. We proceeded in the same manner with lycopodium powder distributed in thin glass tubes ranging from 20 to 8 mm. in diameter, but in only two instances did we get the dust to fall in figures which could be considered reliable for the determination of wave-length. With the cylinders d^5 and f^5 the lycopodium fell into periodic loops 3.83 and 3.27 cm. in length respectively. These values divided into the speed of sound at the given temperature give frequencies of 4511 and 5361 as against 4608 and 5461.33 calculated for these particular cylinders by the makers. Koenig³ was inclined to believe that calculation gave values slightly too high; thus the importance of calibration becomes apparent if the cylinders are to be used for accurate work. It would seem, however, that the Kundt dust method is not very suitable for use with the cylinders. We spent two weeks of vacation-time in fruitless effort to get results, and the only report of the success of this method with the cylinders is Schwendt's brief mention. On the other hand, since calculation and calibration agree here to within 2%, we may perhaps assume that the cylinders as calculated and marked by their manufacturers are accurate for clinical work and class demonstrations, even though calibration will be necessary in research work.

We have used the cylinders at Clark University to determine the

¹ For a discussion of this method as applied to the calibration of high acoustic frequencies, see E. B. Titchener, *Experimental Psychology*, vol. 2, part 2, pp. 32ff.

² A. Schwendt, Experimentelle Bestimmungen der Wellenlänge und Schwingungszahl höchster hörbarer Töne, *Pflüger's Archiv*, 75, 1899, p. 356.

³ R. Koenig, Ueber die höchsten hörbaren und unhörbaren Töne, *Wied. Ann.*, N. F. 69, 1899, p. 723.

tonal TR of sixteen observers, all of whom had had experience in psychological observation. Each observer was seated comfortably in a chair with his back to the cylinders at a distance of four feet, and was given the following instructions: "When the stimulus is presented, you are to report 'yes' if you hear a tone, and 'no' if you hear no tone. Try to report immediately. If you are doubtful of your judgment, say so." Preliminary practice was given to train O and to enable E to determine the critical stimulus. The two cylinders immediately on either side of the critical stimulus were used to complete a series of five stimuli, on each of which 100 judgments were taken. The stimuli were presented in haphazard order in series of 50 judgments with a brief pause between series. No observer experienced more than a temporary initial difficulty in recognizing the presence or absence of tone, and doubtful judgments were rare. They were permitted but not recorded. The whole experiment required about an hour. The accompanying table shows the percentage of affirmative judgments on each of the five stimuli for each observer.

TABLE

Relative frequencies of the judgment "Yes," meaning heard-tonal-quality, for struck steel cylinders of the frequencies indicated. Sixteen observers, one session each. One hundred judgments on each of five stimuli. The frequencies are calculated and not calibrated; see text.

Obs.	CALCULATED FREQUENCY AND MUSICAL NOTE									
	10922.67	12288.	13653.33	15360.	16384.	18432.	20480.	21845.33	24576.	27306.67
	f ⁶	g ⁶	a ⁶	b ⁶	c ⁷	d ⁷	e ⁷	f ⁷	g ⁷	a ⁷
1	100	100	92	15	1					
2			100	100	58	9	0			
3			100	100	88	14	0			
4			100	100	87	8	0			
5			100	100	100	8	0	0		
6			100	100	100	9	0	0		
7				100	100	78	8	0		
8				100	100	67	0	0		
9				100	100	76	0	0		
10				100	100	84	0	0		
11				100	100	85	5	0		
12				100	100	100	0	0		
13				100	100	95	11	0		
14					100	100	29	0	0	
15					100	100	83	6	0	
16						100	100	81	0	0
Average	100	100	99.5	94.7	90.6	58.3	13.9	5.4	0	0

1. The table shows that differences between individuals are much greater than the variations of the single individual from judgment to judgment. Although the d of about 18,000 is most often the critical stimulus there were cases in which the e and f above and the c , b and a below were critical. The instrument, therefore, provides a means for the determination of individual differences, though the number of stimuli is too few to render the calculation of a limen possible, and though the frequencies as calculated are inaccurate within a small per cent.

2. It is extremely probable that under conditions of greater practice not more than one cylinder would turn out to be critical, that all cylinders of lesser frequency would give 100% affirmative judgments and all cylinders of greater frequency no affirmative judgments. Eight of our sixteen observers give this result even under our conditions of little practice. It is also probable that greater practice would produce more often the results given by observer 12, for whom no critical stimulus was present in the series. He always heard tone for b , c , and d and never tone for e and f . He was, it must be added, a more practiced observer than many of the others, and tended for this reason to reject doubtful judgments.

3. In general the cylinders indicate that the limen is less than 20,000 vibrations. The limens for cylinders cited by Titchener⁴ are 20,000 vs. Stumpf mentions the "fast allgemein angenommene Tongrenze von 20,000 Schwingungen."⁵ If we take the averages in our table and compute a limen by Urban's method (phi-gamma hypothesis) we get a value of 18,610 vs. The limen is also dependent upon intensity, which is seldom controlled in experiments and almost never calibrated. Nevertheless it would seem that the recent theories of vowel sounds that require a c of 32,000 vs. must be failing to take account of the facts of the limen.

4. Observer 1, who has the lowest limen, is older than any of the other observers. There is, however, no other evidence of age differences. Observer 1 is between 40 and 50 years of age; observers 2, 6, and 12 are between 30 and 40; all the other observers are between 20 and 30. It happens that the three observers with the highest limens are the most musically trained.

5. One observer, in characterizing the quality of the high tones, described it as a "singing" sound and likened it to a hiss. This observation suggests that even in instruments so little vocal as struck steel cylinders vowel-quality may be present. It is possible, however, that the "singing" sound arises from the beating of the two adjacent tones that Koenig thinks these cylinders produce.⁶

6. Our work contrasts strikingly with work by the Galton whistle in that doubtful judgments with the cylinders are unusual. The scarcity of doubtful judgments is, of course, to be accounted for in part by the use of stimuli so far above and below the limen, but it also appears that doubtful judgments are exceptional even for the critical stimulus. If this conclusion is borne out in further investigation, it will be desirable to use cylinders for liminal determinations instead of the whistle. The psychologist would need to have made up, however, a set of at least thirty cylinders lying within the octave $g^6 = 12288$ to $g^7 = 24576$.

⁴ *Op. cit.*, 41.

⁵ *Bericht über den VI Kongress für experimentelle Psychologie*, 1914, p. 327.

⁶ Koenig, *op. cit.*, p. 722.

⁷ Titchener, *op. cit.*, p. 40.

7. Although intensity is a factor affecting the limen,⁷ its control does not appear to be difficult with this instrument. The determinations of relative frequency given in our table are not significantly altered by slight variations in the strength of the actuating blow of the metal hammer nor by the distance of the observer from the apparatus. A light, hard, rubber hammer in place of the brass gives, however, a noticeably lower limen.

8. The set of cylinders as it stands is extremely useful for demonstrational purposes. We have used it with great success in a small classroom, 21 x 30 ft., seating about 25 persons, to demonstrate individual differences. The observers consistently fail to hear tone at different points in the series and their judgments are apparently not greatly altered by suggestion from the other members of the class. It remains to be seen whether the same demonstrational experiment can be performed for large introductory courses with one or two hundred students.